Prospect and Future of Solar Dryer for Agricultural and Marine Product: Perspective Malaysia

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Abstract: Solar dryer is very environment friendly and will enhance energy conservation. However, one of the main disadvantages of solar energy system is the problem associated with the intermittent nature of solar radiation and the low intensities of solar radiation in solar thermal systems. Hence, many innovative ways of using solar dryer for drying of agricultural and marine products. The new solar collector and the storage system designs are essential for increasing the performance of the solar dryer. The solar dryers developed and presented in this paper have the advantages of heat storage, auxiliary energy source, integrated structure control system and can be use for a wide range of agricultural and marine products.

Keywords: Solar dryer, design, performance, V-groove solar collector, double-pass solar collector, PVT

1. Introduction

Solar energy is the world's abundant permanent and environmentally compatible source of energy. Conversion to clean energy sources such as solar energy would enable the world to improve the quality of life throughout the planet Earth, not only for humans, but also for its flora and fauna as well. Most agricultural and marine products that are intended to be stored must be dried first in an effort to preserve the quality of the final product. Most of the agricultural and marine products in Malaysia are dried under the open sun. There is requires large open space area, and very much dependent on the availability of sunshine, susceptible to contamination with foreign materials such as litters, dusts and are exposed to rodents, insect and birds [1,2]. As an alternative to open sun drying, solar drying system is one of the most attractive and promising applications of solar energy systems. It is renewable and environmentally friendly technology, also economically viable in most developing countries [3]. The present status of post harvest drying technology for selected tropical agricultural produce is shown in Table 1 [4]. The objective of this paper is the design and performance on air based of different types of commercial scale solar dryers, and its prospect in Malaysia.

Table 1. The present status of post harvest drying technology for tropical agricultural and marine produces [4]

Produce	Present Drying System	Energy Source	Drying Time
Paddy	Open drying Fixed bed ryer Moisture extraction unit	Open Sun Diesel Diesel/Electric	5 – 6 hours 4 –5 hours 2 –3 hours
Cocoa	Sundry on cement/tray Kerosene drying Burner blower Rotary drying	Open Sun Kerosene Kerosene/Diesel Diesel	6 days 35 – 40 hours 36 hours 45 –48 hours
Coffee	Sundry	Open Sun	14 days
Pepper	Sundry	Open Sun	7 days (black pepper) 3 days (white pepper)
Tobacco	Conventional curing	Rubber wood LNG	100 hours 100 hours
Tea	Drying chamber	Diesel	25 min at 95°C
Banana	Sundry	Open Sun and wood for smoking	1 day
Anchovies	Sundry Fixed bed dryer	Open Sun Diesel	7 days 5 – 7 hours
Rubber	Sundry	Open Sun and wood for smoking	1 day

2. Solar Dryer with V-Groove Solar Collector

Fig. 1 and Fig. 2 show the schematics and photograph of the forced solar dryer with V-groove collector. The dryer consists of the collector, the drying chamber, fan and the auxiliary heater. The solar collector is of the V-groove type and the collector area is about 15 m^2 as shown in Fig.3. An average output temperature of 50°C can be achieved with a flow rate of 15.1 m^3/min and an average solar radiation of 700 W/m^2 and ambient temperature of 27 – 30°C. Experimental studies on the performance of a solar assisted drying system on herbal tea, chilies, and noodles have been conducted. Hot air is discharged into the drying chamber from outlet duct, which is strategically located for optimum performance. A 10 kW auxiliary heat source has been used for continuous operation and more effective temperature control [5,6].

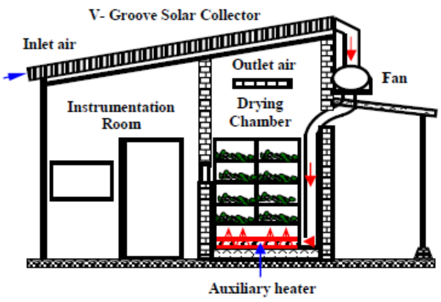

Fig. 1. The schematics of forced convection solar dryer with V-groove collector

Fig. 2. The photograph of forced convection solar dryer with V-groove collector

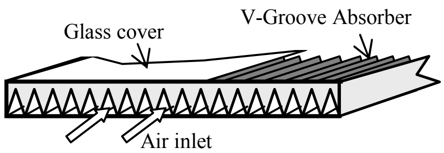

Fig. 3 The back-pass V-groove solar collector

Fig. 4 shows the energy requirement for the drying process of herbal tea. Herbal tea or green tea contains many organic compounds and the processing requirements differ depending on specifications on the types of tea to be produced. Discoloration of herbal tea will occur if the drying process is delayed. Fresh tealeaves have an initial moisture content of 87% (wet basis). Drying is required to lower the final moisture content of 54 % (wet basis). This will allow the green color of the tea to be maintained. The auxiliary heater is on if the drying chamber temperature is below 50 °C. The flow rate is fixed at 15.1 m^3/min. The initial weight of the fresh tealeaves is 10.03 kg and the final weight is 2.86 kg. The drying process started at 8:00 and ended at 18:00. The total energy required to maintain a drying chamber temperature of 50 C is 60.2 kWh. The auxiliary energy contribution is 17.6 kWh. Hence, solar energy contributes 42.6 kWh during the process and contributes approximately 70.2 % of the overall energy requirement. To further decrease the weight to 2.86 kg, further drying is required. The drying process is continued until 20:00 and the contribution of solar energy in the total energy requirement dropped to 56.3 %.

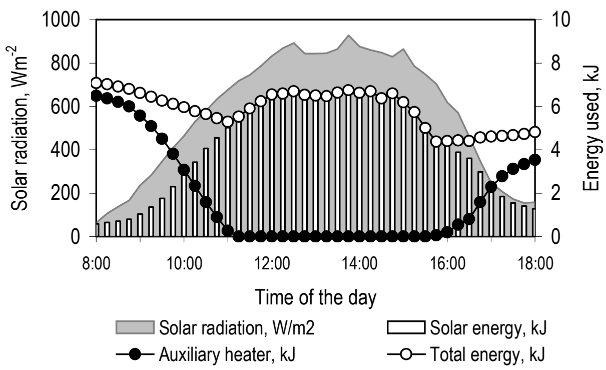

Fig. 4. Energy consumption during drying

Table 2 shows the summary of the experimental results and observations for both continuous and daytime drying processes for red chilies. Also shown are the energy usage of the auxiliary heater and the fan. The red chilies are dried from a moisture content of 80% (wet basis) to a final moisture content of 10% (wet basis). For continuous drying, the solar dryer is operated until the red chilies reached the final moisture content. The auxiliary heater is on if the drying chamber temperature falls below the set temperature. For daytime drying, the solar dryer is operated from 8:00 AM to 6:00 PM until the red chilies reached the final moisture content. The solar energy

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contribution is 24% and 60% of the total energy requirement for the continuous and daytime drying, respectively.

Table. 2. Performance of forced convection solar dryer with V-groove collector for red chilies

Parameters	Daytime Drying	Continuous Drying
Initial weight (kg)	23.13	26.67
Final weight (kg)	4.63	5.32
Initial moisture content (% wet basis)	82	82
Final moisture content (% wet basis)	11	11
Mass flow rate (m^3/min)	16.7	16.7
Set temperature (^oC)	60	50
Drying temperature (^oC)	58-62	48-52
Drying time (hours)	35	58
Auxiliary energy (kWh)	95	299
Solar energy (kWh)	123	94
Fan energy (kWh)	4.8	7.9
Overall heat collection (thermal) efficiency (%)	40-65	40-65
Overall drying efficiency (%)	20-25	20-25

A solar dryer with rotating rack drying chamber is installed at the Green Energy Technology Innovation Park, UKM Malaysia in 2012. The dryer is classified as a forced convection indirect type. Photograph of solar dryer is shown in Fig.5. The solar drying consists of auxiliary heater, fans, rotating rack drying chamber and the back-pass V-groove solar collector. The solar dryer has been test on 24 kg red chili. It is divided equally and then placed on 8 trays is shown Fig. 6.

Fig. 5. Photograph of a solar dryer with rotating rack chamber

Fig.6. Photograph of red chili in rotating rack drying chamber

Table 3 shows the summary of the experimental results and observations for daytime drying process for red chilies using forced convection solar dryer with V-groove solar collector. Also shown are the energy usage of the auxiliary heater and the fan. The red chili is dried from a moisture content of 80% (wet basis) to a final moisture content of 10% (wet basis). The solar dryer is compared with open sun drying, which for open sun drying of 65 h obtained. However, saving in drying time of 52.3% for solar dryer over open sun drying obtained [7].

Table 3 Performance of forced convection solar dryer with V-groove collector for red chilies [7]

Parameters	Unit	Value
Initial weight (sample)	kg	1.25
Final weight (sample)	kg	0.25
Initial weight (total)	kg	24
Final weight (total)	kg	4.8
Initial moisture content (wet basis)	%	80
Final moisture content (wet basis)	%	10
Drying temperature	^oC	50
Mass flow rate	kg/s	0.07
Fans and motor energy	kWh	15
Solar energy	kWh	179.68
Drying time	h	31

Fig.7 shows photograph of hybrid solar dryer for salted fish in Johor. It is classified as a forced convection indirect type. The solar dryer consists of the V-groove solar air collector, diesel burner, fans, rotating rack drying chamber and PV array. Six collectors are connected in series with the total area is 13.8 m^2. A diesel engine is equipped with an on/off controller. It has been attached to the system in order to provide continuous heat as required by the drying commodity. The drying chamber temperature can be controlled by setting the temperature at the required drying temperature.

Fig.7. Photograph of salted silver jewfish in hybrid solar dryer with rotating rack chamber

Table 4 shows the summary of the experimental results and observations of hybrid PV-forced convection solar dyer for salted silver jewfish. And shown are the energy usage of the fans and the energy input by the additional energy source. The required drying time and performance are also shown. Also shown are the initial and final moisture content (wet basis) [8].

Table 4 Performance of PV-forced convection solar dryer with V-groove collector for salted silver jewfish [8]

Parameters	Unit	Value
Initial weight (sample)	g	220
Final weight (sample)	g	80
Initial weight (total)	kg	51.26
Final weight (total)	kg	21.73
Initial moisture content (wet basis)	%	64
Final moisture content (wet basis)	%	10
Drying temperature	^{o}C	50
Mass flow rate	kg/s	0.0778
Fans and motor energy	kWh	4.5
Diesel burner energy	kWh	25.82
Solar energy	kWh	59.62
Drying time	h	8
Volume diesel	L	2

Fig.8 shows the schematics of the PV-forced convection solar dryer with V-groove collector. This drying system uses a custom designed parallel flow V-groove type collector. A fan powered by photovoltaic source assisted the airflow through the drying system. A funnel with increasing diameter towards the top with ventilator turbine is incorporated into the system to facilitate the airflow during the absence of photovoltaic energy source. The solar dryer also includes two 12 V, 1.2 A d.c.-fan attached to the intake of chimney. This drying system is designed with high efficiency and portability in mind so that it can readily be used at plantation sites where the crops are harvested or produced. A daily mean efficiency about 44% with mean air flow rate 0.16 kg/s has been achieved at mean daily radiation intensity of 800W/m^2. Daily mean temperature of air entering the drying chamber under the above condition is 46.8^{o}C. On a bright sunny day with instantaneous solar intensity about 600W/m^2, the temperature of air entering the drying chamber of 45.8^{o}C has been measured. In the absence of photovoltaic or in natural convection flow, the instantaneous efficiency decreased when solar radiation increased. The instantaneous efficiency recorded is 35% and 27%, respectively at 570W/m^2 and 745 W/m^2 of solar radiation. The temperatures of drying chamber for the same amount of solar radiation are 42.8^{o}C and 48.8^{o}C, respectively. Thus, the solar dryer shows a great potential for application in drying process of agricultural and marine products.

Fig. 8. The photograph of PV-forced convection solar dryer with V-groove collector

Fig.9 shows photograph of the PV-forced solar dryer with V-groove collector for seaweed in Semporna, Sabah. The solar dryer is of the batch type. The solar collector is of the back-pass V-groove. PV panels are use to run the fans.

Solar Energy Research Institute (SERI) of Universiti Kebangsaan Malaysia has successfully implemented a drying mechanism and technology for the drying of seaweeds at Pulau Selakan, Sabah using solar thermal with the grant provided by Department of Fisheries (DOF), as show in Fig.10.

A hybrid solar dryer using V-Groove Technology (a patented SERI technology) enhanced using a green house effect has overcome the conventional open dryings of seaweeds technical issues and increase the livelihoods of the community farmers in Pulau Selakan, Sabah. The drying system employed not only a hygienic way of drying methods but also improve the productivity of the farmers. However, the drying design temperature achieved is limited to below 50^{o}C to protect the quality of the dried seaweeds.

Fig. 9. The photograph of PV-forced convection solar dryer with V-groove collector

Fig. 10. The photograph of hybrid V-groove technology and solar house dryer for seaweed

3. Solar Dryer using the Double-Pass Solar Collector with Fins

The schematic diagram of the solar dryer and the double-pass solar collector with fins are shown in Fig. 11 and 12. The main components are solar collector array, auxiliary heater, blower, and drying chamber. The size of the chamber is 4.8 m in length, 1 m width and 0.6 m in height. The four collectors are set in series. The collector area is 11.52 m^2, the mass flow rate is between 0.05 – 012 kg/s and the average drying 50- 65^{o}C. The solar dryer is used to dry seaweed. The seaweed industry has been carried out by communities, associations as well as individuals. Seaweed is widely used in production of food and medical products and industry manufacture at present. Problems faced by the people of seaweed farmers are raining days, requirement of large space for open drying and long drying time. Under open sun drying conditions usually it take 10-14 days for it to be 10% of original weight. The solar drying system has been evaluated for drying seaweed. The initial and final moisture content of seaweed are 90% (wet basis) and 10% (wet basis) respectively. The drying time is about of 14 h at average solar radiation of about 544 W/m^2 and air flow rate 0.06 kg/s. The collector, drying system and pick-up efficiencies were found to be 37, 27 and 92% respectively for 40 kg seaweed [9,10].

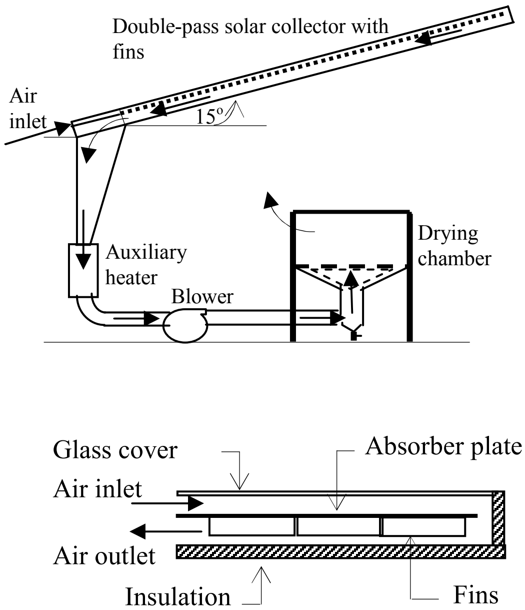

Fig. 11. The schematic of the solar dryer using double-pass solar collector with fins

Fig. 12. Photograph of the solar dryer using double-pass solar collector with fins

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Table 5 shows the summary of the experimental results and observations for daytime drying process for red chilies using forced convection solar dryer using double-solar collector with fins. The red chili is dried from a moisture content of 80% (wet basis) to a final moisture content of 10% (wet basis) in 33 h. The solar dryer is compared with open sun drying, which for open sun drying of 65 h obtained. However, saving in drying time of 49% for solar dryer over open sun drying obtained [11].

Table 5 Performance of solar dryer using double-pass solar collector with fins for red chili [11]

Parameters	Unit	Value
Initial weight (total)	kg	40
Final weight (total)	kg	8
Initial moisture content (wet basis)	%	80
Final moisture content (wet basis)	%	10
Mass flow rate	kg/s	0.07
Average solar radiation	W/m^2	420
Average ambient temperature	^{o}C	30
Average drying chamber temperature	^{o}C	44
Average ambient relative humidity	%	62
Average drying chamber humidity	%	33
Drying time	h	33
Blower energy	kWh	4.13
Solar energy	kWh	160.43
Evaporative capacity	kg/h	0.97
Overall heat collection (thermal) efficiency	%	28
Overall drying efficiency, up to 10% wet basis	%	13
Pick-up efficiency, up to 10% wet basis	%	45

The forced convection solar dryer using double-pass solar collector with fins has been installed at the OPF FELDA Kuantan, Malaysia. Photograph of solar dryer is shown in Fig. 13. The solar dryer has been evaluated for drying the oil palm fronds. For 100 kg palm oil fronds, the drying time is about of 3 drying day in sunny day (without heater) from an initial moisture content of 60% to the final moisture content of 10% (wet basis). A temperature of 55^{o}C can be reached at a solar radiation level of 650 W/m^2, and mass flow rate of 0.13 kg/s, the overall system efficiency is about 20% [12].

Fig. 13. Photograph of the solar dryer using double-pass solar collector with fins

4. Solar Dryer using the Double-Pass Collector with Integrated Storage System

Fig. 14 shows solar dryer using the double-pass collector with integrated storage system. The solar dryer consists of solar air collector, blower, auxiliary-heater and drying chamber. Fig. 15 shows the double-pass type solar collector. The second or lower channel of the solar collector is filled up with porous media which acts as heat storage system. The auxiliary heater is equipped with an on/off controller. The set temperature is 50^{o}C based on the temperature of the inlet to the drying chamber. Arranging this type of collector is not as simple as the V-Groove single pass collector. The collector arrangement is shown in Fig.16. The solar collector array consists of 6 solar collectors as shown in Fig.13. The outlet temperature does not drop drastically as in any conventional solar air collector. The outlet temperature goes down gradually in the evening even at low solar radiation levels. The reason for this is because of the presence of the porous media in the second channel that acts as the heat storage media for the system. The solar dryer using double-pass solar collector with porous media can be used for drying oil palm fronds from moisture content of about 63% to moisture content of about 15%, for drying time of about 7 h. The system efficiency is about 25 – 30% and evaporative capacity 1.26 kg/h. In addition, the auxiliary heater is used during unfavorable solar radiation conditions, especially in the morning and the evening [13].

Fig. 14. The photograph of solar dryer using double-pass solar collector with integrated storage system

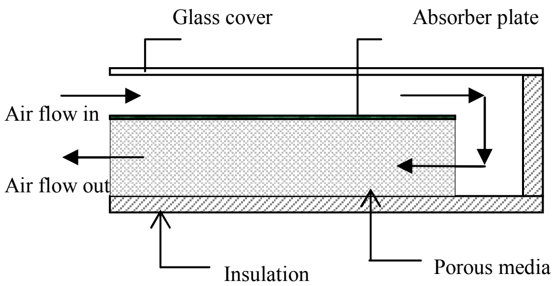

Fig.15. The schematic of a double-pass solar collector with porous media in the second channel

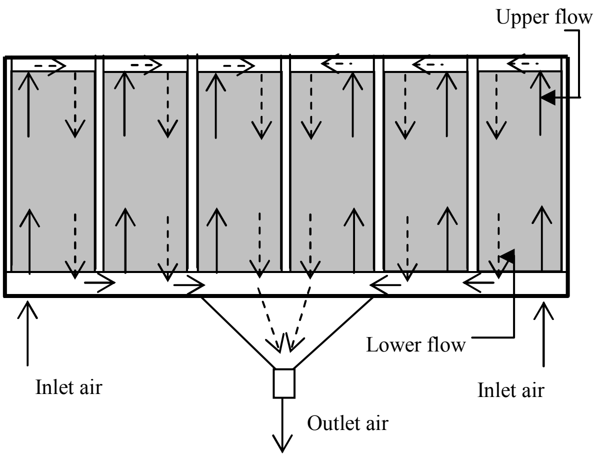

Fig.16. The collector arrangement for the solar dryer

5. Solar Dryer with Photovoltaic Thermal Collector

The schematic diagram of the solar dryer and the double-pass solar collector with compound parabolic concentrator (CPC) and fins are shown in Fig. 17 and 18. The main components are PVT solar collector array, controller, blower, and drying chamber.

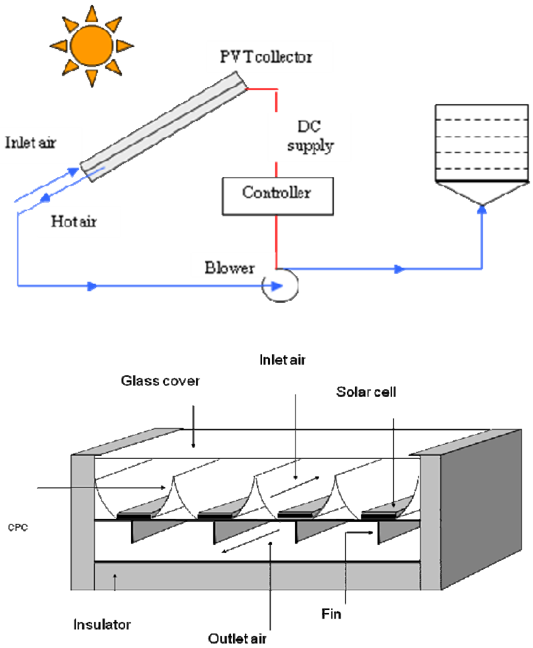

Fig. 17. The schematic of the solar dryer using double-pass solar collector with photovoltaic solar thermal collector

Fig. 18. The photograph of the solar dryer using double-pass solar collector with photovoltaic solar thermal collector

The application of solar energy can be broadly classified into two categories; thermal energy systems which converts solar energy into thermal energy and photovoltaic energy system which converts solar energy into electrical energy. The vital component in solar energy system is the solar collections systems. Two solar energy collection systems commonly used are the flat plate collectors and photovoltaic cells. Normally, these two collection systems are used separately. It has been shown that these two systems can be combined together in a hybrid photovoltaic thermal (PVT) energy system. The term PVT refers to solar thermal

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collectors that use PV cells as an integral part of the absorber plate. The system generates both thermal and electrical energy simultaneously. The number of the photovoltaic cells in the system can be adjusted according to the local load demands. In conventional solar thermal system, external electrical energy is required to circulate the working fluid through the system. The need for an external electrical source can be eliminated by using this hybrid system. With a suitable design, one can produce a self-sufficient solar collector system that required no external electrical energy to run the system.

The double-pass concepts was later extended to include heat transfer augmentation features such as a fins for enhancing heat removal by convective and conductive heat transfers and also compound parabolic collectors for solar radiation booster. The performance of the double-pass solar collector can be further increased by including these features. The intensity of the solar radiation incident upon the photovoltaic panel can be increase by installing a booster concentrator. Fig.19 shows the performance of various PVT including single, double-pass system, double pass with compound parabolic solar collector and fins [14,15].

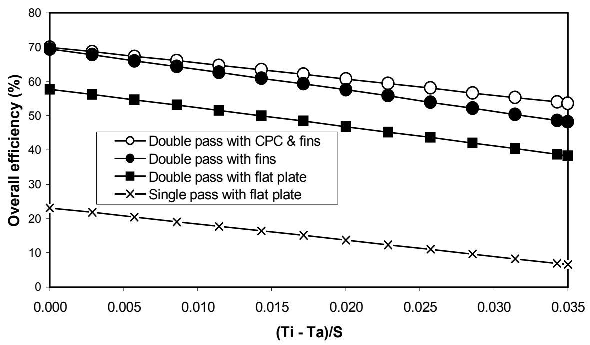

Fig. 19. Overall performance of PVT solar collector with single, double-pass system, double pass with compound parabolic solar collector and fins

6. Conclusions

The design and performance on air based of different types of commercial scale solar dryers, and its prospect in Malaysia. Other limitations were given by the availability of appropriate drying equipment which is technically and economically feasible and the lack of knowledge how to process agricultural and marine products. Up to now only a few solar dryers who meet the technical, economical and socio-economical requirements are commercially available. Most solar dryers are simple, low power, short life, and comparatively low efficiency-drying system. The solar dryers presented in this paper are high efficiency, high power, long life and expensive drying systems. However, deciding factor for any solar driers should be based on economics. Economic decisions are about choices among possible alternatives of action in the future. The approach is to minimize input (cost) for a give output (benefits), or to maximize the output (benefits) from a given input (cost). The simple solar will have lower output compared to the more sophisticated solar drying systems. Hence, the payback period for such higher efficiency and productivity solar dryers should be much lower that the simple solar dryers. In addition, the solar dryers presented in this paper have very stable output temperature and higher performance. Materials for construction for these solar are also available locally.

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